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Assessment of the Atmospheric Effects of Stratospheric Aircraft

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This grant was initiated to enable and encourage collaboration with the University of Oslo research group (under Professor Ivar Isaksen) in the assessment of aircraft effects from a proposed fleet of high-speed civil transport aircraft. The grant enabled Prof. Isaksen to visit and work with Professor Cicerone at UC Irvine and to complete the assessment calculations included in the most recent HSRP/AESA assessment. Appropriate sections of that program report are enclosed as a final report demonstrating the effectiveness of the grant.

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The Atmospheric Effects of Stratospheric Aircraft: Interim Assessment Report of the NASA High-Speed Research Program

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Chapter 7

Model Calculation of HSCT Effect

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INTRODUCTION

The assessment results presented in this chapter are from six two-dimensional zonal-mean models (AER, CAMED, GSFC, LLNL, NCAR, and OSLO, see Table 1). The purpose of this chapter is to present results from calculations using the emissions data presented in Chapter 4 and discuss the factors that affect the uncertainties in the calculated results. While the discussion will focus on the recent results obtained using the latest emission scenarios and parameterization of heterogeneous chemistry, it also draws on the results obtained over the previous 2 years.

MODEL FEATURES, SIMILARITIES, AND DIFFERENCES

The models that provided results for this document are representative of the models being used for ozone assessment studies connected with the chlorine/ozone problem (WMO, 1992). The results for aircraft assessment may be sensitive to model features that have not been tested previously. Previous model validations have concentrated on the effect of increased chlorine in which the source for chlorine is more or less uniformly distributed through the middle and upper stratosphere. Aircraft emissions are deposited close to the tropopause. The results should depend on the ability of the model to simulate the dynamics of the lower stratosphere and upper troposphere with respect to synoptic-scale motions and the exchange of mass between the stratosphere and the troposphere. Increases in NO_y in the lower stratosphere lead to large adjustments of the HO_x and ClO_x chemical cycles. Validation of various mechanisms is also more difficult since the changes in each cycle are likely to be small compared with those observed in the polar regions.

There are common features among the models because of similarity in the basic approach, and because improvements to the models were made as a result of several model intercomparison workshops (Jackman et al., 1989b; Prather and Remsberg, 1993). However, differences still exist among the models. We will try to make use of these different approaches to get a better idea of the uncertainties associated with the model predictions.

Treatment of Photochemistry

Reaction rates and photolysis cross sections used in the calculations are taken from JPL-92 (De More et al., 1992). The radiative transfer calculations in the models differ in their treatment of multiple scattering. There are also significant differences in photolysis rates which have a significant contribution from the spectral interval containing the Schumann-Runge bands (see Prather and Remsberg, 1993). However, these have only a small impact on the calculated ozone changes.

For a test case in which the long-lived species such as ozone and total odd nitrogen are held fixed, the calculated radical concentrations in three of the models (AER, GSFC, and LLNL) are in good agreement with each other and with ATMOS sunset measurements (see Prather and Remsberg, 1993, Section M.).

The models also differ in the diurnal treatments used to calculate the long-lived trace gases. The AER model uses an explicit diurnal integration. The other models use diurnally averaged production and loss rates to calculate daytime average constituent concentrations. In some cases, precalculated factors computed off-line with a diurnal model are used in this calculation. The diurnal treatment is particularly important for determining the rate of heterogeneous reaction of N_2O_5 with H_2O, because N_2O_5 exhibits a large diurnal variation. The similarity among the model calculated results on ozone changes would suggest that this is treated in an adequate manner.

Table 1. Models Providing Results in the Assessment

AER	Atmospheric and Environmental Research Inc.,	M. Ko and D. Weisenstein
CAMED-θ	University of Cambridge and University of Edinburgh	J. Pyle, R. Harwood, and J. Kinnersley
GSFC	NASA Goddard Space Flight Center	C. Jackman, A. Douglass, E. Fleming, and D. Considine
LLNL	Lawrence Livermore Laboratory	D. Wuebbles and D. Kinnison
NCAR	National Center for Atmospheric Research	G. Brasseur and X. Tie
OSLO	University of Oslo	I. Isaksen

Table 2. Boundary Conditions for Background Atmospheres

Species	Concentration in "1990"- 3.3 ppb Chlorine	Concentration in "2015"-3.7 ppb Chlorine	Concentration in "2015"-2.0 ppb Chlorine
CFC-11	253 ppt	260 ppt	124 ppt
CFC-12	434 ppt	510 ppt	359 ppt
CFC-113	44 ppt	70 ppt	49 ppt
CFC-114	7 ppt	10 ppt	7.8 ppt
CFC-115	5 ppt	8 ppt	7.2 ppt
CCl_4	103 ppt	100 ppt	34 ppt
HCFC-22	92 ppt	200 ppt	3.7ppt
CH_3CCl_3	145 ppt	150 ppt	0 ppt
Halon-1301	2.6 ppt	6 ppt	2.6 ppt
Halon-1211	2.0 ppt	2 ppt	0.2 ppt
CH_3Cl	600 ppt	600 ppt	600 ppt
CH_3Br	15 ppt	15 ppt	15 ppt
N_2O	308 ppb	330 ppb	330 ppb
CH_4	1685 ppb	2050 ppb	2050 ppb
CO_2	350 ppm	390 ppm	390 ppm

Note:
Units, mixing ratio by volume : 1 ppt = 1 part per trillion, 1 ppb = 1 part per billion, 1 ppm = 1 part per million.
The total chlorine content is about 3.7 ppb in the "2015" atmosphere.
While it is recognized that other boundary conditions affecting tropospheric chemistry such as CO and NO_x will change with time, it is recommended that each model keeps its present day reference troposphere unchanged in the simulations.

Table 3. Summary of Assessment Scenarios*

Experiment	Aircraft†	Mach number & NO_x EI for HSCT	Chlorine Background
I	Modified subsonic + HSCT, scenario C	Mach 1.6, EI=5	3.7 ppbv
II	Modified subsonic + HSCT, scenario D	Mach 1.6, EI=15	3.7 ppbv
III	Modified subsonic + HSCT, scenario E	Mach 2.4, EI=5	3.7 ppbv
IV	Modified subsonic + HSCT, scenario F	Mach 2.4, EI=15	3.7 ppbv
V	Modified subsonic + HSCT, scenario D	Mach 2.4, EI=15	2.0 ppbv
VI	Modified subsonic + HSCT, scenario G	Mach 2.4, EI=45	3.7 ppbv

*Change in ozone is calculated relative to the background atmosphere with a subsonic fleet as described in scenario B in Chapter 4.
†Scenarios are defined in Chapter 4.

Table 4a. Calculated Percent Change in the Annual Averaged Column Content of Ozone Between 40°N and 50°N

Scenarios	AER	GSFC	LLNL	OSLO	CAMED	NCAR
I : Mach 1.6, NOX EI=5*	-0.04	-0.11	-0.22	0.19	0.69	-0.01
II : Mach 1.6, NOX EI=15*	-0.02	-0.07	-0.57	0.55	0.48	-0.60
III : Mach 2.4, NOX EI=5*	-0.47	-0.29	-0.58	0.18	0.38	-0.26
IV : Mach 2.4, NOX EI=15*	-1.2	-0.86	-2.1	0.12	-0.45	-1.8
V: Mach 2.4, NOX EI=15†	-2.0	-1.3	-2.7	-0.42	-1.1	-2.3
VI : Mach 2.4, NOX EI=45*	-5.5	-4.1	-8.3	-1.9	-2.8	-6.9

Table 4b. Calculated Percent Change in the Annual Averaged Content of Ozone in the Northern Hemisphere

Scenarios	AER	GSFC	LLNL	OSLO	CAMED	NCAR
I : Mach 1.6, NOX EI=5*	-0.04	-0.12	-0.18	0.13	0.63	-0.04
II : Mach 1.6, NOX EI=15*	-0.02	-0.14	-0.48	0.39	0.63	-0.54
III : Mach 2.4, NOX EI=5*	-0.42	-0.27	-0.50	0.15	0.25	-0.25
IV : Mach 2.4, NOX EI=15*	-1.0	-0.80	-1.8	0.05	-0.26	-1.5
V : Mach 2.4, NOX EI=15†	-1.7	-1.2	-2.3	-0.43	-0.80	-1.9
VI : Mach 2.4, NOX EI=45*	-4.6	-3.6	-7.0	-1.8	-2.1	-5.1

*Relative to a background atmosphere with chlorine loading of 3.7 ppbv, corresponding to the year 2015.
†Relative to a background atmosphere with chlorine loading of 2.0 ppbv, corresponding to the year 2060.

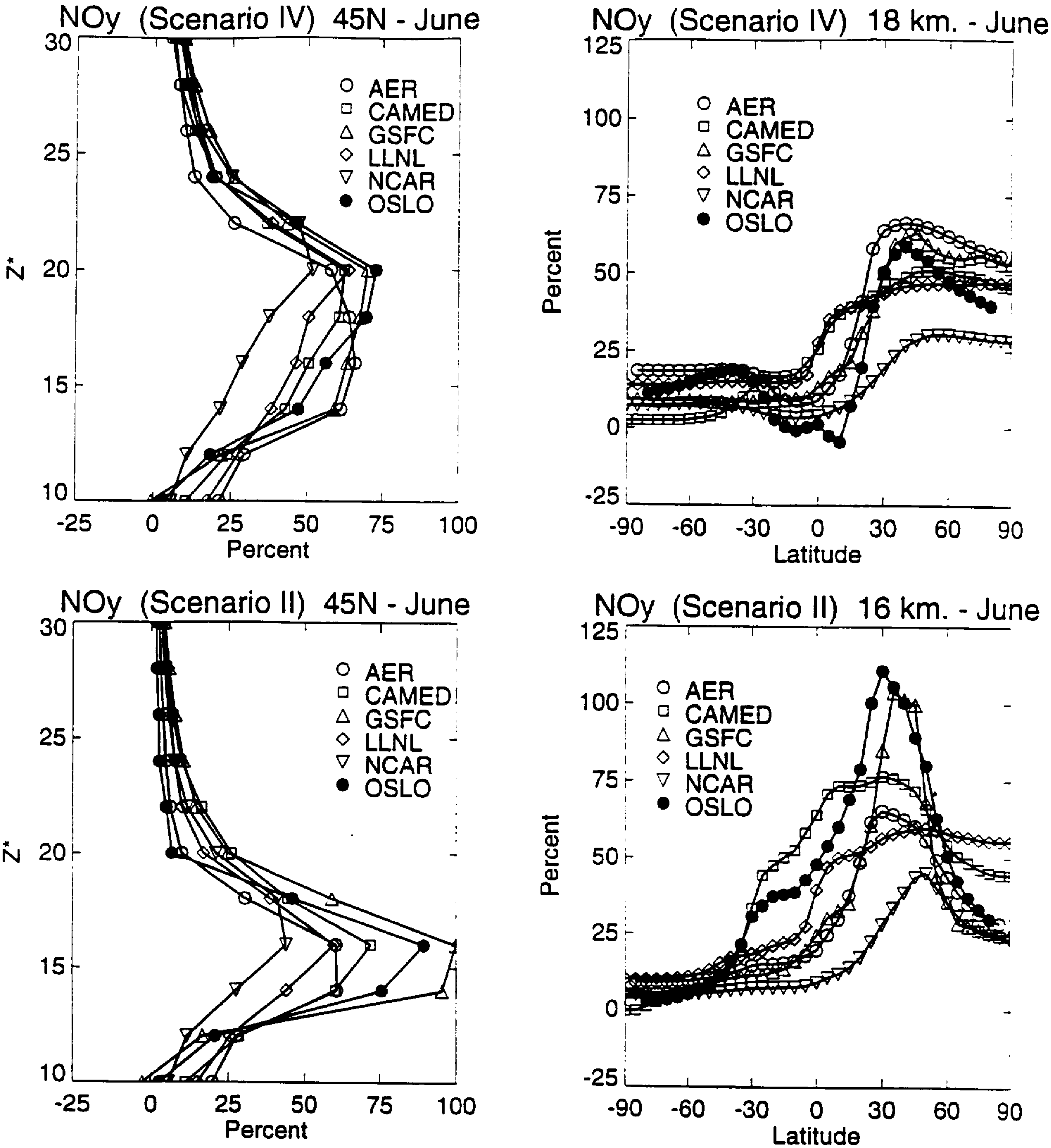

Figure 1. Model-calculated percent change in concentrations of NO_y: (a) Calculated altitude profile for the percent change of NO_y for the Mach 2.4, NO_x EI=15 case at 45°N for June; (b) calculated altitude profile for the percent change of NO_y for the Mach 1.6, NO_x EI=15 case at 45°N for June; (c) calculated latitude profile for the percent change of NO_y for the Mach 2.4, NO_x EI=15 case at 18 km for June; (d) calculated latitude profile for the percent change of NO_y for the Mach 1.6, NO_x EI=15 case at 16 km for June.

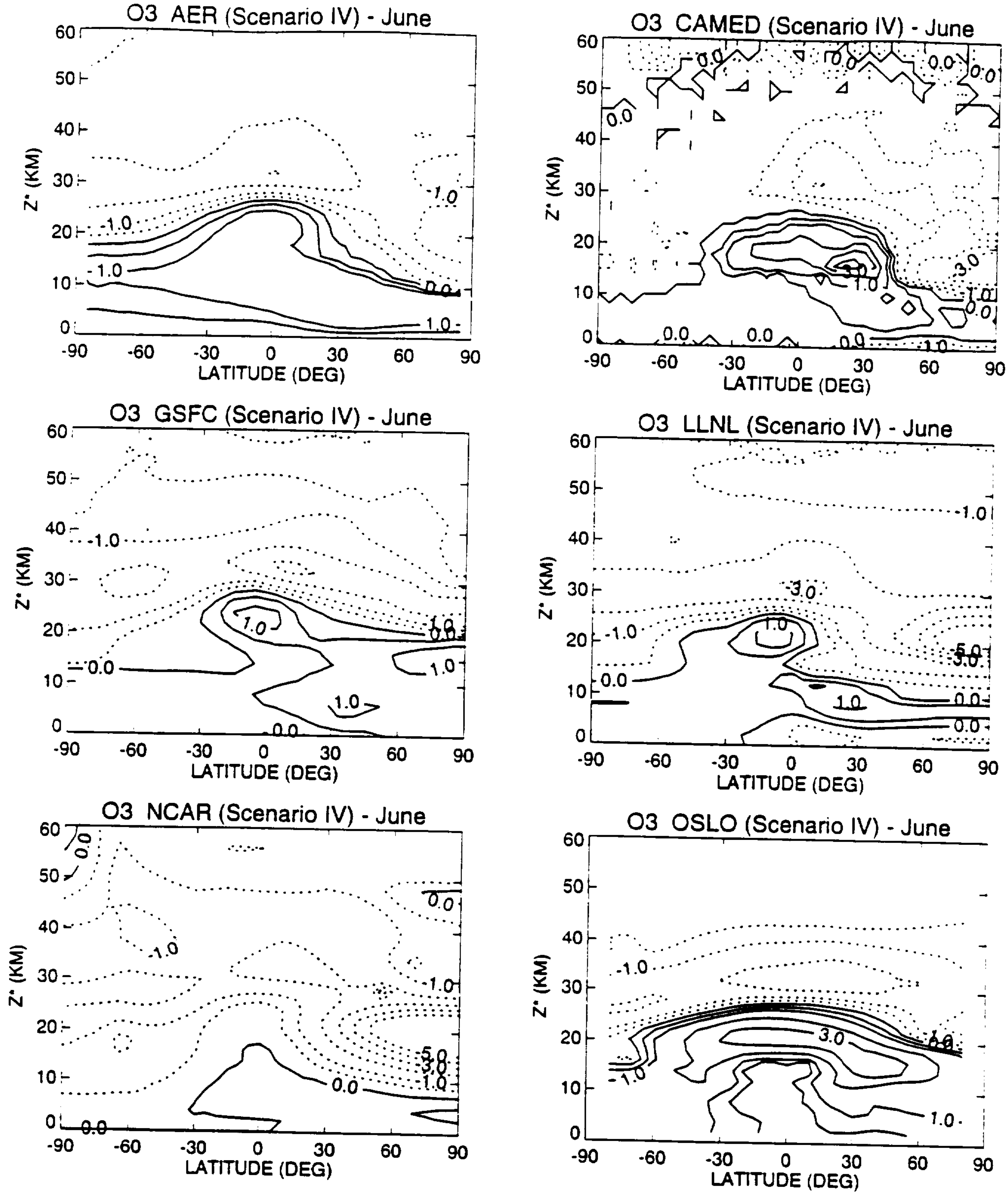

Figure 3. Model-calculated percent change in local ozone for June for the Mach 2.4, NO_x EI=15 fleet in the 2015 atmosphere. The contour intervals are -4%, -3%, -2%-1%, -0.5%, 0%, 0.5%, 1%, 2%, 3%, 4%.

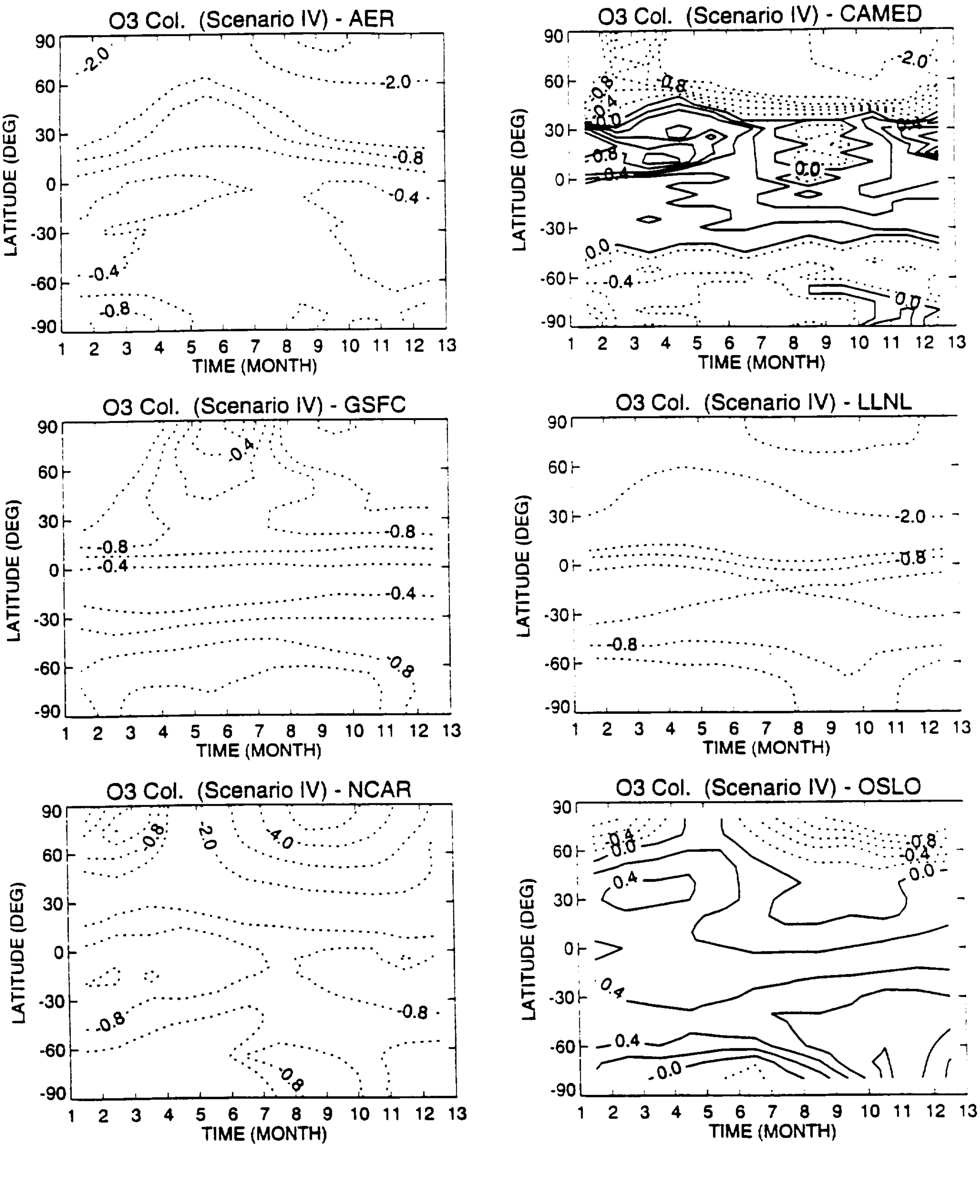

Figure 4. Model-calculated change in the column abundannce of ozone for the Mach 2.4, NO_x EI=15 fleet in the 2015 atmosphere. The contour intervals are -6%, -5%, -4%, -3%, -2%, -1%, -0.8%, -0.6%, -0.4%, -0.2%, 0%, 0.2%, 0.4%, 0.6%, 0.8%, 1%, 2%.

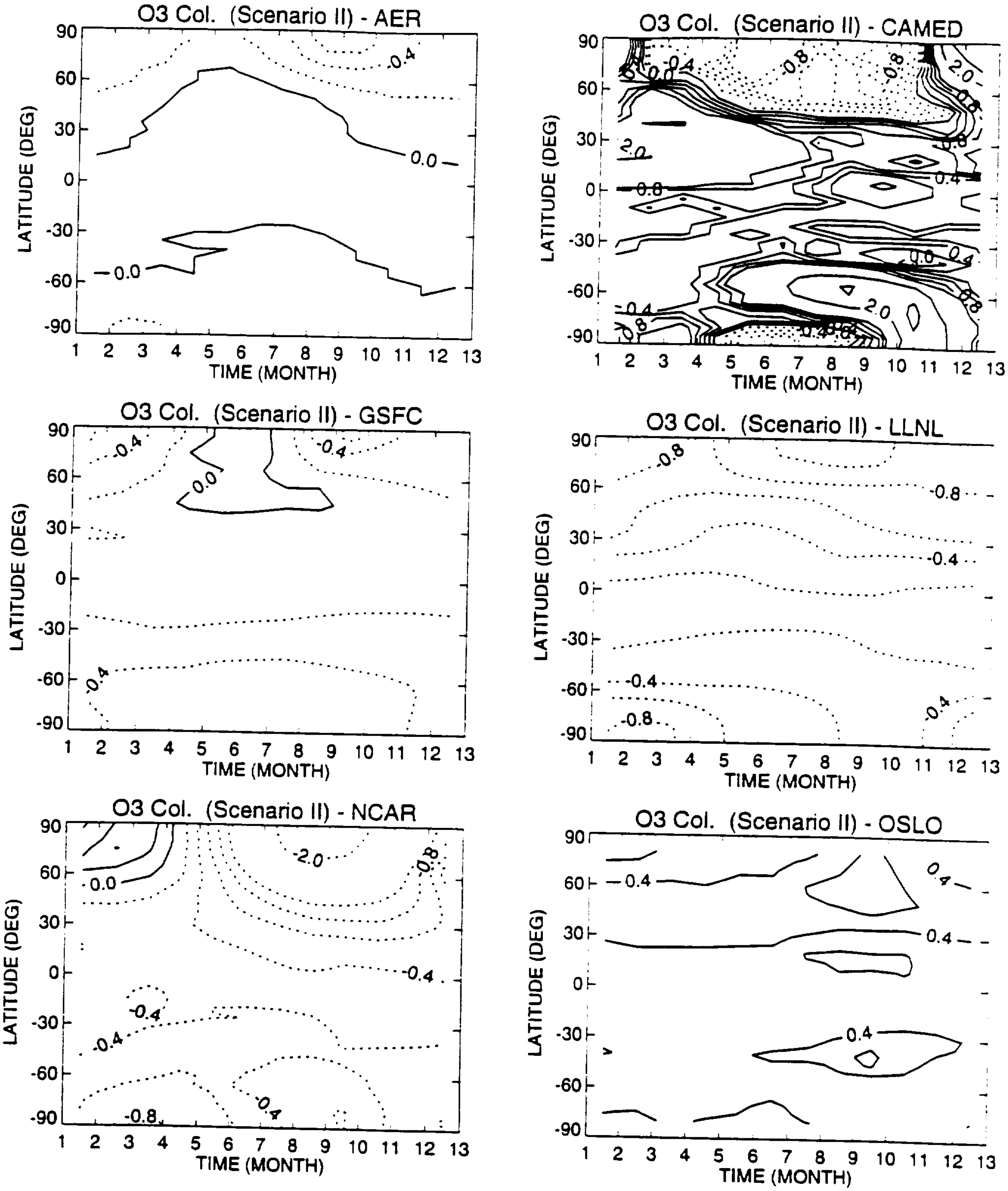

Figure 5. Model-calculated change in the column abundannce of ozone for the Mach 1.6, NO_x EI=15 fleet in the 2015 atmosphere. The contour intervals are -6%, -5%, -4%, -3%, -2%, -1%, -0.8%, -0.6%, -0.4%, -0.2%, 0%, 0.2%, 0.4%, 0.6%, 0.8%, 1%, 2%.

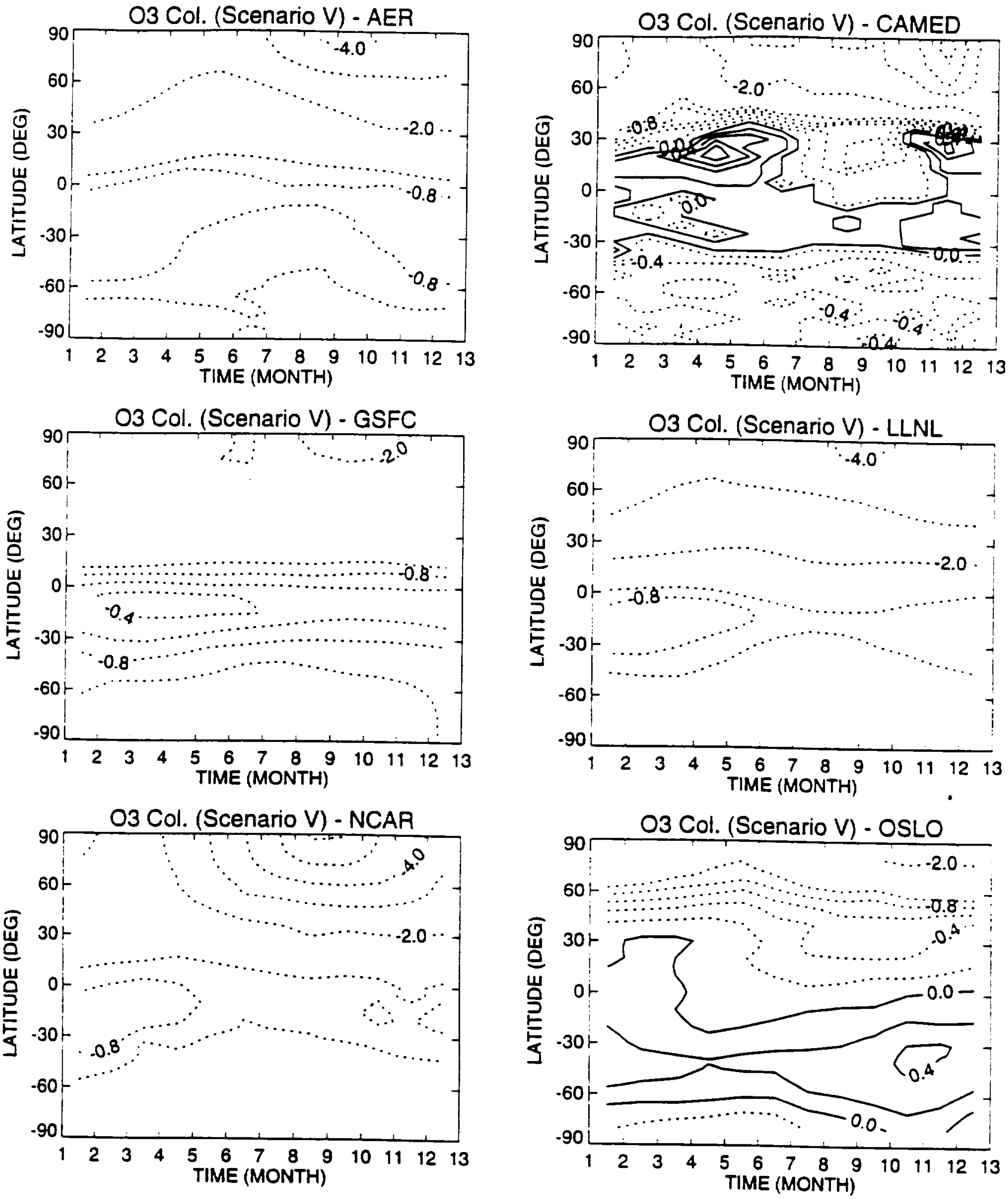

Figure 6. Model-calculated change in the column abundannce of ozone for the Mach 2.4, NO_x EI=15 fleet in the 2.0 ppbv chlorine background. The contour intervals are -6%, -5%, -4%, -3%, -2%, -1%, -0.8%, -0.6%, -0.4%, -0.2%, 0%, 0.2%, 0.4%, 0.6%, 0.8%, 1%, 2%.